

Recent results on two-photon and tau physics at BABAR

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We present a measurement of the total width $\Gamma_{tot}^{\eta_c}$ and mass M_{η_c} of the η_c meson with the BABAR detector at the PEP-II B -factory at SLAC. The results based on a data sample of 88 fb^{-1} are $\Gamma_{tot}^{\eta_c} = (33.3 \pm 2.5(\text{stat.}) \pm 0.8(\text{syst.})) \text{ MeV}/c^2$ and $M_{\eta_c} = (2983.3 \pm 1.2 \pm 1.8) \text{ MeV}/c^2$. An enhancement observed around $3.63 \text{ GeV}/c^2$ can be interpreted as an evidence for the $\eta_c(2S)$ state. In addition a preliminary measurement of the τ lepton lifetime using 30.2 fb^{-1} is described. The measured τ lifetime is: $\tau_\tau = (290.8 \pm 1.5(\text{stat.}) \pm 1.6(\text{syst.})) \text{ fs}$.

1 Measurement of the η_c meson mass and width

1.1 Introduction

The mass and the width of the charmonium ground state $\eta_c(1S)$ are not well established. The world average¹ of the total width and mass is $\Gamma_{tot}^{\eta_c} = 16.0_{-3.2}^{+3.6} \text{ MeV}/c^2$ and $M_{\eta_c} = (2979 \pm 1.5) \text{ MeV}/c^2$, respectively. The η_c is expected to decay dominantly via two-gluon annihilation, so that $\Gamma_{tot}^{\eta_c} \approx \Gamma_{gg}^{\eta_c}$. Hence the ratio of the total width of the η_c to its two-photon partial width is predicted by NLO perturbative QCD²:

$$\frac{\Gamma_{tot}^{\eta_c}}{\Gamma_{\gamma\gamma}^{\eta_c}} \approx \frac{9\alpha_s^2}{8\alpha^2} \cdot \frac{1 + 4.8\alpha_s/\pi}{1 - 3.4\alpha_s/\pi} \quad (1)$$

Using² $\alpha_s = 0.28 \pm 0.02$ and the world average¹ of $\Gamma_{\gamma\gamma}^{\eta_c} = 7.5 \pm 0.8 \text{ keV}$ gives $\Gamma_{tot}^{\eta_c}$ as $25.4 \pm 6.0 \text{ MeV}/c^2$, a value higher than but still consistent with the world average.

1.2 Fit of the mass spectrum

The data sample consists of an integrated e^+e^- luminosity of 88 fb^{-1} , including runs on and below the $\Upsilon(4S)$ resonance. The η_c mesons are produced by two-photon interactions. They are selected via the decay channel $\eta_c \rightarrow K_S^0 K^\pm \pi^\mp$ with $K_S^0 \rightarrow \pi^+ \pi^-$, where in addition the e^- and e^+ are required to escape through the beam pipe.

The mass spectrum is shown in figure 1. A large peak can be seen at the η_c mass, a smaller one at the J/ψ mass. J/ψ are produced by e^+e^- annihilation where one electron emitted a hard photon by initial state radiation.

The width of the η_c is of the same order of magnitude as the mass resolution of the detector. Therefore the detector resolution has to be precisely known in order to extract the η_c width from the observed peak in the invariant mass spectrum. The width¹ of the J/ψ of $87 \pm 5 \text{ keV}$ is much

smaller than the detector resolution. Hence the observed width of the J/ψ peak is completely determined by the resolution.

The mass spectrum is fitted in the mass range from 2.4 to 3.6 GeV/ c^2 . The η_c is represented by a convolution of a non-relativistic Breit-Wigner function and a Gaussian. The J/ψ peak is fitted with a single Gaussian. The standard deviation σ_{η_c} of the Gaussian, which describes the mass resolution at the η_c peak, is constrained to a value 0.8 MeV/ c^2 lower than that for the J/ψ . This difference of 0.8 MeV/ c^2 of the mass resolution was obtained from Monte Carlo events. The background is represented by the function: $A \cdot e^{-B \cdot mass}$. The free fit parameters are the J/ψ mass $M_{J/\psi}$, the mass difference $M_{\eta_c} - M_{J/\psi}$, the η_c width $\Gamma_{tot}^{\eta_c}$, the mass resolution of the J/ψ $\sigma_{J/\psi}$, the normalization and slope of the background and the number of events in the η_c and J/ψ peaks. The result of the fit is presented in table 1.

Table 1: Result of the unbinned maximum likelihood fit of the mass spectrum. The resolutions of the J/ψ and the η_c peaks are $\sigma_{J/\psi}$ and σ_{η_c} , respectively .

	$\Gamma_{tot}^{\eta_c}$ [MeV/ c^2]	$M_{J/\psi} - M_{\eta_c}$ [MeV/ c^2]	$M_{J/\psi}$ [MeV/ c^2]	$\sigma_{J/\psi}$ [MeV/ c^2]	σ_{η_c} [MeV/ c^2]
fit	33.3 ± 2.5	113.6 ± 1.2	3094.0 ± 0.8	7.5 ± 0.8	$\sigma_{J/\psi} - 0.8$

1.3 Systematic errors

A source of a systematic error on $\Gamma_{tot}^{\eta_c}$ is the uncertainty of the detector mass resolution. This contribution is estimated to 0.4 MeV/ c^2 by using the mass resolution for the η_c obtained from Monte Carlo events for the fit. The systematic error due to the parametrization of the background is estimated by varying the mass range of the fit. A variation from 2.4-3.6 GeV/ c^2 to 2.7-3.3 GeV/ c^2 changes the value of $\Gamma_{tot}^{\eta_c}$ by 0.7 MeV/ c^2 .

The reconstructed masses $M_{J/\psi}$ and M_{η_c} are shifted in Monte Carlo simulation by -1.1 MeV/ c^2 compared to the values used as input. This bias does not affect the mass difference. However the fitted J/ψ mass is still shifted by -1.8 MeV/ c^2 from the well established PDG value¹ of (3096.87 ± 0.04) MeV/ c^2 after correction of the bias observed in the Monte Carlo simulation. We take this shift as a systematic error on the η_c mass since we do not know its source. The unknown mass shift is not necessarily the same for the η_c and the J/ψ because the angular distribution of their decay products are different. The shift could be caused by inhomogeneities in the magnetic field which may not be correctly modeled in Monte Carlo.

1.4 Evidence for the $\eta_c(2S)$ state

The $\eta_c(2S)$ is not experimentally established yet¹. Its theoretically predicted mass is in the range³ 3583 to 3640 MeV/ c^2 . There exist two experimental results^{4, 5} which are not in agreement.

The upper right histogram of figure 1 shows the $K_s^0 K^\pm \pi^\mp$ invariant mass spectrum extended to higher masses. An enhancement can be seen at about 3.63 GeV/ c^2 which lies within the predicted mass region of the $\eta_c(2S)$ and hence is interpreted as an evidence of this state. The mass spectrum is fitted using a Breit-Wigner function convoluted with a Gaussian to describe the enhancement. The standard deviation of the Gaussian is set to 8.5 MeV/ c^2 which was estimated from a Monte Carlo sample. The fit results in $\Gamma_{tot}^{\eta_c(2S)} = (20 \pm 10)$ MeV/ c^2 and $M_{\eta_c(2S)} = (3633.3 \pm 5.0)$ MeV/ c^2 . The $\eta_c(2S)$ peak contains 86 ± 23 events.

The systematic error associated to the $\eta_c(2S)$ width due to an uncertainty of the mass resolution is 1.6 MeV/ c^2 . The background parametrization gives a contribution of 3.3 MeV/ c^2 to the systematic error on the total width.

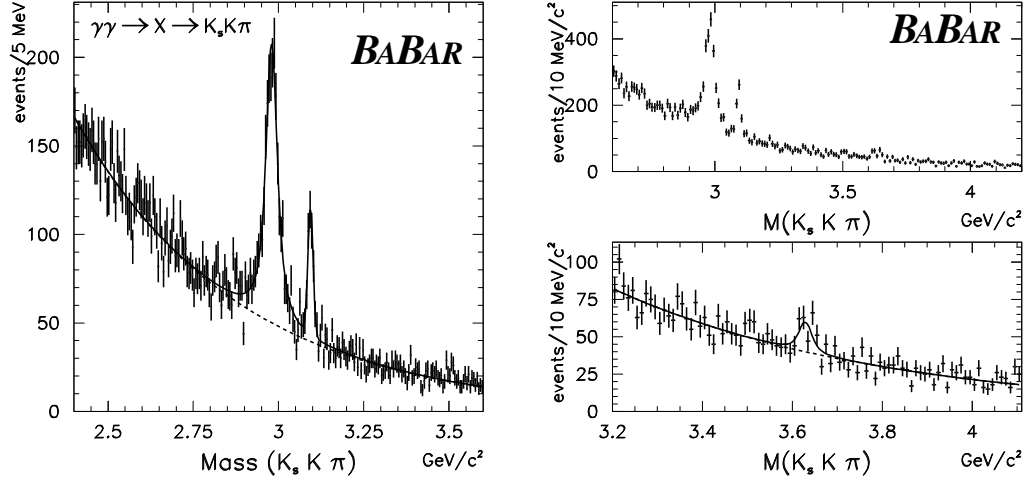


Figure 1: Various histograms of the $K_S^0 K^\pm \pi^\mp$ invariant mass spectrum. The large peak around 2983 MeV/ c^2 is the η_c , the peak next to it is the J/ψ . An evidence of a $\eta_c(2S)$ signal can be seen around 3630 MeV/ c^2 .

In summary, we have measured the mass and width of the η_c meson $M_{\eta_c} = (2983.3 \pm 1.2(stat) \pm 1.8(syst))$ MeV/ c^2 and $\Gamma_{tot}^{\eta_c} = (33.3 \pm 2.5(stat) \pm 0.8(syst))$ MeV/ c^2 and observed an evidence of the $\eta_c(2S)$. The mass and width of the $\eta_c(2S)$ were measured to $M_{\eta_c(2S)} = (3632.2 \pm 5.0 \pm 1.8)$ MeV/ c^2 and $\Gamma_{tot}^{\eta_c(2S)} = (20 \pm 10 \pm 4)$ MeV/ c^2 , respectively.

The measured value of the total width of the η_c deviates from the world average by more than three standard deviations while the measured mass agrees well with the world average. The mass of the enhancement interpreted as the $\eta_c(2S)$ falls in the theoretically predicted range of the $\eta_c(2S)$ mass.

2 Measurement of the τ lepton lifetime

A measurement of the τ lepton lifetime, combined with the branching ratio of τ into leptons, the τ and μ mass and the μ lifetime, provides a test of lepton universality. This test is experimentally limited by the uncertainties of the τ lifetime and its leptonic branching fraction.

The mean τ lifetime $\langle\tau_\tau\rangle$ is given by

$$\langle\tau_\tau\rangle = \frac{M_\tau}{\langle P_\tau \rangle} \langle\lambda_\tau\rangle, \quad (2)$$

where M_τ is the τ mass, $\langle P_\tau \rangle$ the average τ momentum in the center-of-mass frame and $\langle\lambda_\tau\rangle$ the mean τ decay length. The average momentum is calculated from a Monte Carlo sample. The mean decay length is measured using decays where one τ decays into three charged particles while the other one decays into a single charged particle.

The tracks of the 3-prong τ candidate are projected onto the transverse plane, which is perpendicular to the boost direction of the e^+e^- annihilation. The 3-prong vertex \vec{x}_{3p} in the transverse plane is reconstructed and the transverse decay length $\lambda_{\tau,t}$ is calculated by:

$$\lambda_{\tau,t} = (\vec{x}_{3p} - \vec{x}_{bs}) \cdot \hat{p}_{3p} \quad (3)$$

where \vec{x}_{bs} is the center of the luminous region and \hat{p}_{3p} the unit vector of the 3-prong momentum in the transverse plane. This method of reconstructing the decay length was chosen because it is less dependent on uncertainties of the detector alignment. The decay length in space λ_τ is

calculated by dividing the transverse decay length by the sine of the polar angle of the 3-prong momentum in the center-of-mass system. Figure 2 shows the decay length distribution for τ candidates.

The mean decay length is calculated by averaging over all events. The averaging is done without any error weighting of the events. Instead an azimuthal weighting is done to achieve an uniform azimuthal event distribution. This method of averaging is more robust with regards to uncertainties of the position of the luminous region.

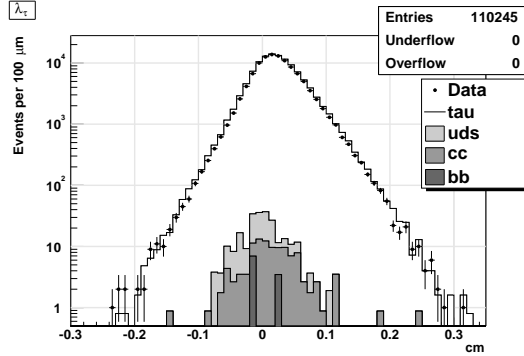


Figure 2: Measured decay length for data and Monte Carlo.

The bias of this analysis method was obtained from a Monte Carlo sample. Its uncertainties are the main contribution (1.3 fs) to the systematic error of the τ lifetime. The detector alignment is another major source of systematic uncertainties (0.7 fs).

The result based on 30.2 fb^{-1} is $\tau_\tau = (290.8 \pm 1.5(\text{stat.}) \pm 1.6(\text{syst.})) \text{ fs}$. It agrees well with the world average of $(290.6 \pm 1.1) \text{ fs}$.

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